Long Range Sediment Tomography--Developing Advanced Experimental Designs

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LONG-TERM GOALS

The long term objective of this research is to develop experimental designs for applying the long range sediment tomography technique in shallow water (30-100 m) over ranges from 10-50 km.

OBJECTIVES

- Continue the analysis of the shot data collected during the ASIAEX experiment in the East China Sea (ECS) in 2001 for inversions of the bottom properties. Some of the results have already been documented and published in the IEEE-JOE Special Issue on "Science and Engineering advances in exploring the Asian Marginal Seas". The attenuation inversion using the shot data is in progress.

- Based on the experience gained from Shelf Break Primer and ASIAEX experiments, modifications and improvements to the long range sediment tomography technique will be explored and studied. The experimental design for the shallow water experiment planned for the New Jersey Shelf in also in progress.

- Explore the possibility of applying the technique to shallower waters (30-80 m). Optimum source frequencies and ranges will be studied using a synthetic test case.

- Develop advanced signal processing techniques which will enhance our ability to identify and extract the modal arrival times. These techniques include matching pursuit algorithms and time-frequency-space-mode processing of the vertical line array data.

APPROACH

Long range sediment tomography technique[1,2,3] has been successfully applied to data from Shelf Break Primer experiment and the East China Sea experiment. The broadband Wide Band Source (WBS) data collected during the ASIAEX- East China Sea (ECS) field study is being analyzed at University of Rhode Island (URI). New techniques for the time- frequency analysis techniques have been developed and applied to the ECS data[4]. The arrival times of individual modes have been used to estimate the sediment compressional speeds and attenuations[1, 2]. Some of the results from this study have been published in the special issue of IEEE-JOE (Potty, et al.[5], Miller et al.[6]).

The ECS data have been used to estimate the compressional wave speed using range dependent linear perturbation and non-linear inversion approaches[7]. In addition we use our inversion scheme to estimate

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14. ABSTRACT
The long term objective of this research is to develop experimental designs for applying the long range sediment tomography technique in shallow water (30-100 m) over ranges from 10-50 km.

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the compressional wave attenuation in the frequency rage 30- 120 Hz. We can use these values to investigate the frequency dependency of attenuation. Results of this study were presented at the special session during the Vancouver meeting of the Acoustical Society of America[8].

The long range sediment technique needs data from only a single hydrophone. A time-frequency analysis of this data will provide the arrival time of many modes. When we collect the data on a Vertical Line Array (as in both Primer and ASIAEX experiments) we can use the data from multiple phones to improve the resolution of the time-frequency diagrams. This will results in accurate estimates of the modal arrival times, which in turn will increase the quality of the inversions results. This array processing will be in addition to pursuing improvements in the time-frequency processing of individual phone data.

WORK COMPLETED

The analysis of the ECS data and design of the 2006 Shallow water experiment (SW'06) are proceeding simultaneously. Compressional wave speeds have been estimated and was published in the IEEE Journal of Oceanic Engineering Special Issue[5]. These values are also compared with other inversions, geophysical surveys and core data[6]. Attenuation inversions of the ECS data are being carried out to estimate the compressional wave attenuation[8]. We follow the inversion technique as described in Potty et al[2].

Rajan *et al*[9]. have developed a method to use the group velocity dispersion relation to determine the range-independent bottom acoustic properties using a linear perturbation approach. This method has been tested with field data by Lynch *et al*[10]. This approach has now been extended to cover range-dependent inversion for the sediment acoustic properties. Results of inversions performed using synthetic data show that the range-dependent properties can be obtained if the experiment consisted of multiple source receiver combinations. This approach is now being applied to broadband WBS data collected during the ECS experiment[7].

Efforts are also underway to design an optimum source-receiver deployment pattern for the Shallow Water Experiment (2006). We are working closely with Mohsen Badiey (U. of Delaware), Kyle Becker (APL, Penn State) and Rajan.

RESULTS

Inversion for compressional wave attenuation is carried out based on modal attenuation ratios. A time-frequency analysis of the broad band data from the Wide Band Sources (WBS) produces the dispersed arrivals. The ratio of the amplitude of various modal arrivals is used to estimate the modal attenuation coefficient. The depth dependent attenuation coefficient is then estimated using a linear inversion[2].

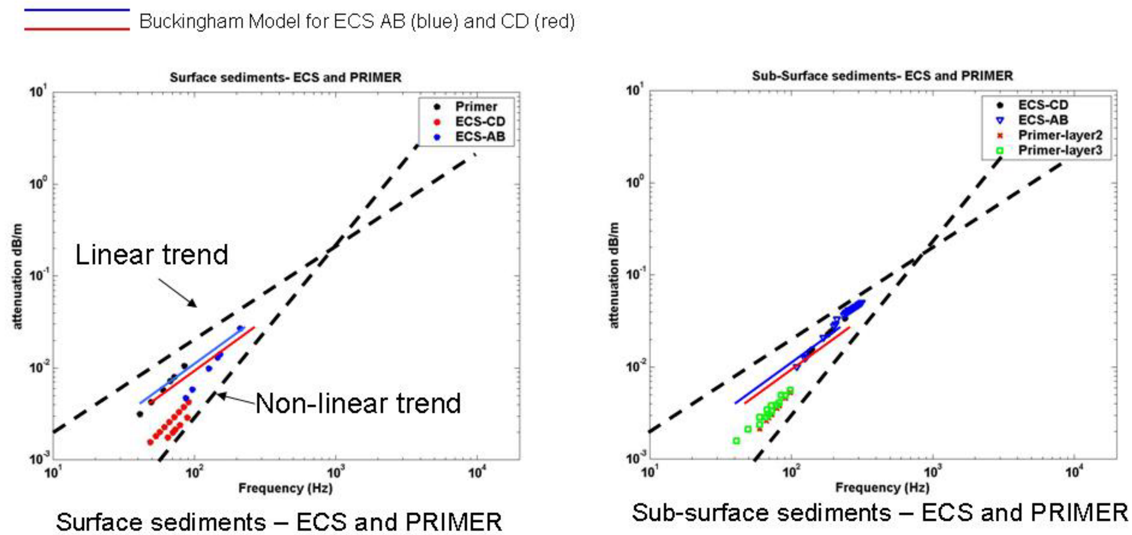

Figure 1. Compressional attenuation values from inversion for the surface and sub-surface sediments. Results from inversions using Primer data and ECS are shown. ECS-AB refers to data from the south side and ECS-CD refers to north- west side of the experiment area.

Figure 1 shows the compressional wave attenuation coefficient obtained based on this inversion. The sediment tomography inversions fall into the frequency band of 50-250 Hz. The left panel shows the attenuation coefficients for the surface layer and the right panel shows the sub-surface layer. The results shown in the figure correspond to Primer and ECS data. East China Sea sediments in the Northwest side (ECS-AB) tend to follow a linear trend and also resemble PRIMER surface sediments. On the other hand East China Sea sediments in the south side (ECS-CD) tend to follow a non-linear trend. This indicates a spatial variability in surface sediment properties which has been verified by direct measurements[6]. In the case of sub-surface sediments Primer data tend towards non-linear trend whereas ECS data tends towards linear (even though at different frequency bands). More importantly these results show no spatial variability in the ECS sub-surface sediments. Knobles et al[11] also arrived at similar differences in frequency dependence of attenuation in surface and sub-surface sediments. More inversions are being carried out over the entire area to see whether there is any spatial variability.

Figure 2 shows the results from a range dependent perturbation inversion[7]. Two types of sediments were assumed in the experimental area (denoted as Region 1 and 2) and the compressional wave speeds were inverted using this inversion approach. The perturbation approach is based on the following expression for mode travel time perturbation dt_n for a sound speed perturbation of Δc,

$$dt_n = \frac{\partial}{\partial \omega} \int_0^r \int_0^\infty \frac{1}{k_n(\omega)} \frac{\omega^2 \Delta c(s,z)}{c^3(s,z)\rho(s,z)} \left|\phi_n(s,z,\omega)\right|^2 ds dz \qquad (1)$$

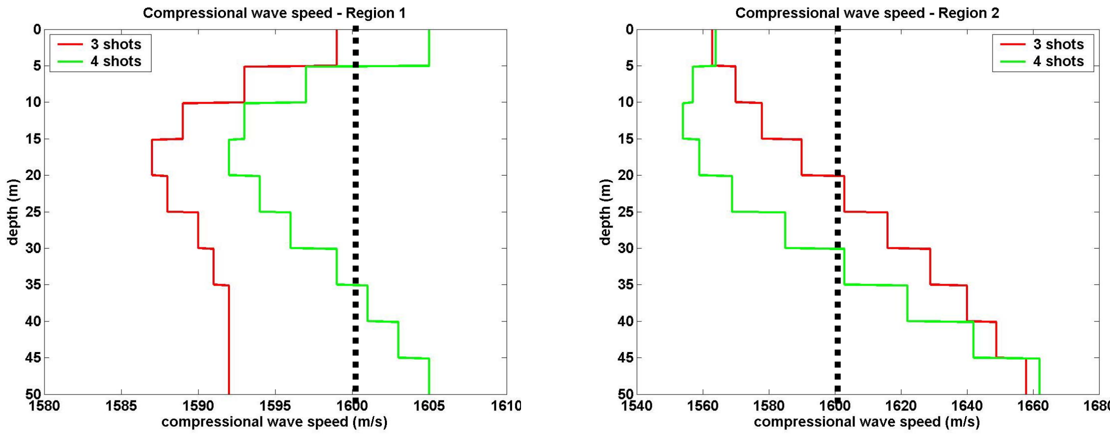

Figure 2. The compressional wave speeds in the sediment in Regions 1 (western side) and (eastern side). Sediment is modelled using 5 m thick layers for the perturbation inversion. The dashed line indicates the starting profile.

where k_n is the eigen value of the nth mode for an assumed background model, *c(s,z)* and $\rho(s,z)$ are the sediment compressional wave speed and density profiles at range 's' for the background model, ϕ_n is the eigen function corresponding to the nth mode at that location, ω is the frequency. The double integral can be changed into a double sum as given below.

$$dt_n = \sum_p \sum_q A(s_p, z_q)\Delta c(s_p, z_q) \qquad (5)$$

This double sum can be reduced to a matrix equation which can be solved to determine the quantity $\Delta c(s_p, z_q)$. In converting the integral to a matrix equation we have assumed that the region is discretized in both range and depth. The argument s_p refers to the pth step in range and z_q refers to the qth step in depth. The results shown in Figure 2 also indicates spatial variability in the sediments.

Efforts are underway to design a suitable source deployment pattern for the Shallow Water Experiment in 2006. Unlike Primer and ECS experiments airgun sources will be available as a broadband source. This will provide better definition of source characteristics (depth, range and source level) compared to explosives. On the other hand we expect that only a fewer number of modes will be available for sediment tomography inversions. The appropriate source locations and ranges are being explored in collaboration with Kyle Becker, Mohsen Badiey and S. Rajan.

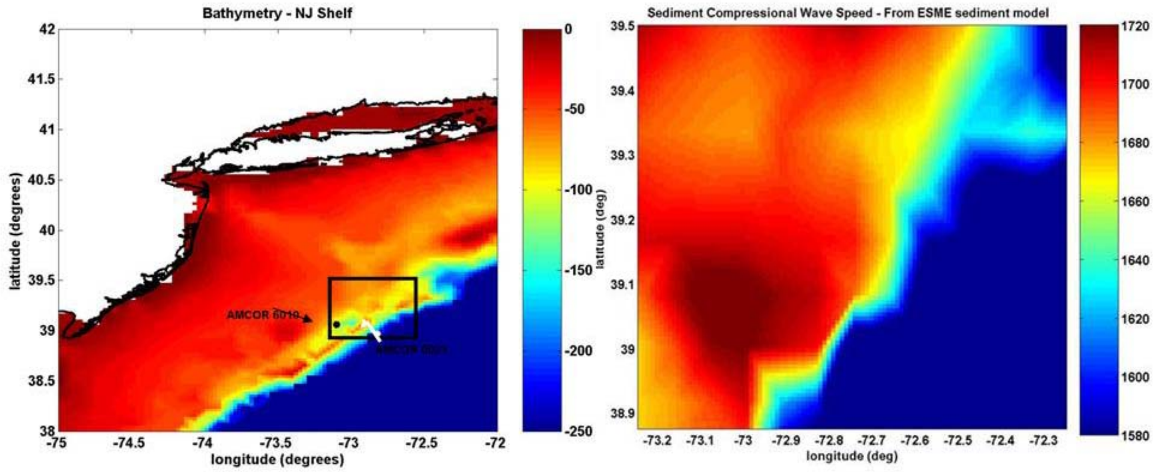

Figure 3. Bathymetry at the shallow water experiment site. Locations of the AMCOR sites 6010 and 6021 are also shown. Right panel shows the sediment compressional wave speed at the experimental location from the ESME sediment module.

Figure 3 shows the bathymetry (from ETOP05 database) and compressional wave speeds in the surface sediments in the proposed experimental area. This data are produced by the ESME sediment model for the East Coast of the US. The major data set contributing to this sediment model is the USGS sediment texture database for the US East Coast. The compressional wave speeds are computed using information from this database (sediment texture, grain size, porosity and clay/sand percentage) using the Buckingham model[10]. It should be noted that data are scarce at water depths greater than 100 m and hence the accuracy of the estimated values at depths beyond 100 m is very low.

IMPACT/APPLICATIONS

This inversion scheme using explosive sources is suitable for rapid estimation of acoustic properties of sediments in shallow water. This method is cost effective as a single sonobuoy and air-deployed explosives can provide the data. Using multiple sources and receivers sediment properties would allow an area to be mapped.

TRANSITIONS

The sediment parameters obtained by this inversion will compliment the forward modeling efforts. Our technique is suitable for forward force deployment when rapid assessment of environmental characteristics is necessary. In addition to naval air ASW applications using sonobuoys and SUS charges, this technique would be compatible with Navy special operations involving autonomous vehicles. In that scenario, the vehicle could drop a small timed charge and receive the acoustic signals at a distance. This would allow the sediment properties to be estimated in the area.

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